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QUASAR PAIRS AND QUASAR'S PECULIAR VELOCITY

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Abstract

The peculiar velocity of quasars is among the most sought data of observational cosmology. This paper discusses a method of determining an upper limit to the peculiar velocity of quasars by means of a statistical analysis of quasar pairs. A preliminary conclusion is that the peculiar velocity in the direction along the line joining two quasars in a pair may not exceed, on an average, one thousand km/sec.

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1. Introduction

Ever since the large scale structure of the universe become a heated subject of cosmology, the peculiar velocities of extragalactic objects have become one of the focal points of observational cosmology. In particular, the discovery of the large scale streaming motion of galaxies[1] has furture strengthened the motivation to study problems related to the peculiar velocity of extragalactic objects. It is clear that, in order to understand the formation of a large scale structure, information about the distribution of the peculiar velocities of extragalactic objects is as important as information about their spatial distribution.

Nevertheless, right now, we know almost nothing about the peculiar velocity of quasars. By employing different methods to conjecture quasar's peculiar velocity, one can obtain quite different results. For instance, if we consider that quasars are likely to be the objects of an earlier stage of galaxies, their peculiar velocity should then be about the same order of that of galaxies, namely, several hundrads of kilometers per second. On the other hand, the distribution of quasars on the Hubble diagram is very dispersive, which would not be completely explainable by the dispersions and variations of quasar's luminosity. Therefore, it may imply that quasars possess higher peculiar velocity than galaxies. Moreover, many quasars are in objects which have radio components moving with apparently separate speeds higher than that of light. This phenomenon is often considered as evidence of the relativistic effects of high speed objects. In this case, we would not be able to rule out that some of the peculiar velocities of quasars are much higher, even comparable to the speed of light.

Therefore, any information regarding quasar's peculiar velocity is very significant. The purpose of this paper is to discuss the possibility of derving such information from quasar pairs. A method of determining an upper limit to the relative velocity between two quasars in a pair is presented. Since quasar samples are still quite poor, it is impossible at this moment to find results with a high confidence. Nevertheless, the method here discussed has already gave a significant conclusion: there is an upper limit of one thousand km/sec to the mean velocity in the direction along the line joining the two quasars in a pair. This result also shows that the methods themselves developed here are effective.

2. Method

Let us consider a sample of quasar pairs. In each pair consisting of i-th and j-th quasars, one has the following data: D -- the distance between the two quasars; and, D_r and D_t -- the respective radial and transversal projections of D. D_r is given by the difference bwteen the redshifts of the two quasars and D_t mainly depends on the angular distance of the two quasars.

It is known that quasar's clustering is weak[2] , namely, the distribution of quasars is almost randomly homogeneous. Therefore, if the pair sample consists of all pairs of quasars in such a randomly homogeneous sample, then the distribution of D should be homogeneous and the distribution of pair's orientation, given by the line joining the two quasars in a pair, should be isotropic. In other words, the distribution of pairs in D_r-D_t space is randomly homogeneous.

From this randomly homogeneous sample, we can make up a subsample(D_{max}), which consists of all pairs with D less than D_{max} . It is easily shown from the homogeneity and isotropy that, for a subsample(D_{max}), the distribution of the number of pairs against D_r is given by

$$N(D_r)dD_r = \frac{3}{2} N_T \left(1 - \frac{D_r^2}{D_{max}^2}\right) d\left(\frac{D_r}{D_{max}}\right) , \qquad (1)$$

where N_T is the total number of pairs in the subsample (D_{max}). The average of D_r is then

$$\overline{D}_r = \frac{1}{N_T} \int_0^{D_{max}} D_r N(D_r)\ dD_r = \frac{3}{8} D_{max} \quad . \qquad (2)$$

Obviously, Eqs.(1) and (2) can be used as two criterions to test the homogeneity and isotropy of the sample. Quasar clustering will lead to a deviation from (1) and (2). Therefore, information on clustering can be found from the deviation between observed $N(D_r)$ and D_r and that given by Eqs.(1) and (2). Nevertheless, clustering is not the problem with which we are concerned in this paper. The important point we want to emphasize here is that the peculiar velocity of quasars will also sometimes lead to a deviation from (1) and (2). Therefore, the observed deviation can provide an upper limit to the peculiar velocity.

Let us consider a simple model in which we assume that the two quasars in every pair are approching each other at an average speed of v. In this case, the observed redshift difference of two quasars i and j in a pair should be given by

$$z_i - z_j = z_i^o - z_j^o - \frac{v}{c}\frac{D_r}{D}\,[1 + (z_i^o - z_j^o)] \ , \tag{3}$$

where z_i^o and z_j^o are the cosmological redshifts of quasars i and j. Therefore, the D_r given by the observed redshift difference $(z_i - z_j)$ is not a real radial distance between quasars i and j. When $(z_i - z_j) \ll 1$ and $D \gg (v/c)(c/H_o)$, H_o being the Hubble constant, the real radial distance D_r^o can be approximately expressed from Eq.(3) as

$$D_r^o = D_r + \frac{v}{c}\frac{c}{H_o}\frac{D_r}{(D_r^2 + D_t^2)^{1/2}} \ , \tag{4}$$

In the case of that the distribution of pairs in D_r^o-D_t space is homogeneous and isotropic, then, from Eq.(4), the distrubition of pairs in D_r-D_t space should be given by

$$N(D_r, D_t)dD_r dD_t \quad (1 + \frac{v}{c}\frac{c}{H_o}\frac{D_r}{(D_r^2 + D_t^2)^{3/2}}\ )\ D_t dD_t dD_r \tag{5}$$

Therefore, for a sample consisting of all pairs with $D = (D_r^2 + D_t^2)^{1/2}$ less than D_{max}, the distribution of pairs against D_r is

$$N(D_r)dD_r = \frac{3}{2}\,N_T\,(1 + \frac{v}{c}\frac{c}{H_o}\frac{1}{D_{max}}\ )^{-1} \times$$
$$[1 - \frac{D_r^2}{D_{max}^2} + \frac{v}{c}\frac{c}{H_o}\frac{2}{D_{max}}\,(1 - \frac{2D_r}{D_{max}} + \frac{D_r^2}{D_{max}^2}\ )]\ d(\frac{D_r}{D_{max}}) \ . \tag{6}$$

The average of D_r now is given by

$$\overline{D}_r = \frac{1}{N_T}\int_0^{D_{max}} D_r\, N(D_r)\, dD_r$$

$$= \frac{3}{8} D_{max}\ (1 + \frac{2}{3}\frac{c}{H_o}\frac{1}{D_{max}})(1 + \frac{v}{c}\frac{c}{H_o}\frac{1}{D_{max}})^{-1}$$

$$\frac{3}{8} D_{max}\ (1 - \frac{1}{3}\frac{v}{c}\frac{c}{H_o}\frac{1}{D_{max}}) \quad . \tag{7}$$

Eqs.(6) and (7) show the deviation of $N(D_r)$ and $\overline{D}_r$ from (1) and (2) due to the peculiar velocity of quasars.

3. Statistical Results

For statistical analysis, we use the quasar sample given by Savage and Bolton[3], which includes quasars in two $5^o \times 5^o$ regions around, respectively, $(02^h, -50^o)$ and $(22^h, -18^o)$ in the southern hemisphere. It is known that Savage-Bolton sample is not complete. Nevertheless, in our statistics, the completeness of the sample is not a necessary condition. We only require that the sample is homogeneous. Many statistics on quasar clustering have been done by using the Savage-Bolton sample because this sample possesses the homogeneity suitable to statistics.

For every pair formed by i-th an j-th quasars in this sample, one can calcuate the distance between the two quasars, D, and its transversal and radial projections, D_t and D_r by, respectively,

$$D = (D_r^2 + D_t^2)^{1/2} , \quad (8)$$

$$D_r = \frac{1}{1 + z_m} \left| \frac{d_i}{1 + z_i} + \frac{d_j}{1 + z_j} \right| , \quad (9)$$

$$D_t = \vartheta_{ij} \frac{1}{2} \left[\frac{d_i}{(1 + z_i)^2} + \frac{d_j}{(1 + z_j)^2} \right] , \quad (10)$$

and

$$d_k = \frac{c}{H_o q_o^2} \left[z_k q_o + (q_o - 1)(-1 + \sqrt{2 q_o z_k + 1}) \right] , \quad (11)$$

where $z_m = (1/2)(z_i + z_j)$ and z_k is the redshift of k-th quasar; ϑ_{ij} denotes the angular distance between the two quasars; and q_o is the deceleration parameter. In the following calculation, we choose $q_o = 1/2$. When $D << c/H_o$, the result does not sensitively depend much on the selection of q_o.

It has been shown that the spatial distribution of quasars in the Savage-Bolton sample is uniform or weakly clustered. This property can also be seen from the distribution of quasar pairs described by Eqs.(8)-(11). Figs.1 and 2 plot the distribution of pair's number with respect to D. For the sake of comparison, Figs.1 and 2 also plot the distribution of the Monte Carlo sample, which is given by an average of 10 Monte Carlo results of randomizations of angular coordinates α and δ. Figs.1 and 2 clearly show that no significant difference between the distributions of the Savage-Bolton sample and the Monte Carlo sample can be found in the region of (02^h, -50^o). In the region (22^h, -18^o), however, the pair's number in the Savage-Bolton sample in the interval of D, being about 50-100 Mpc, exceeds that given by Monte Carlo sample. That is, the quasar distribution in the region (02^h, -50^o) is uniform, while that in (22^h, -18^o) is weakly clustered. This result is the same as that obtained by other methods of testing clustering[2]. Therefore, this sample is suitable for the statistical method developed in the previous section.

Next, we consider subsample(D_{max}), which consists of all the quasar's pairs with three dimensional distance D less than D_{max}. Figs.3 and 4 show the histograms of $N(D_r)$ of the subsamples with D_{max} = 50 and 100 Mpc, in which N_T is the total number of pairs. The solid curves in Fig.3 and 4 are given by Eq.(1). It is obvious from Figs.3 and 4 that there are no significant deviation in the distributions $N(D_r)$ of the Savage-Bolton sample of $(02^h, -50^o)$ from that of a homogeneous-isotropic sample. This means that the peculiar velocity of quasars should, at least, be small enough so that there is no significant influence on the distribution $N(D_r)$. In the region of $(22^h, -18^o)$, Fig.4 shows that there are deviations of sample's $N(D_r)$ from that of homogeneous-isotropic one. However, Fig.4 also shows that the deviation of subsample D_{max} = 100 Mpc is more small than that of subsample D_{max} = 50 Mpc. This means that these deviations are probably due to the weak clustering of quasars on the scale less than 100 Mpc in the region $(22^h,$ $-18^o)$. Therefore, these deviations may not be evidence that quasar's peculiar velocity in the region $(22^h, -18^o)$ must be larger than that of $(02^h. -50^o)$.

The results of $\overline{D}_r$ are listed in Table 1, in which the upper limit v_{up} to peculiar velocity is found from Eq.(7) as follows

$$v_{up} = 8H_o \left| \overline{D}_r - \frac{3}{8} D_{max} \right| . \tag{12}$$

All results of v_{up} listed in Table 1 are around a thousand km/sec. Therefore, if all deviation of $\overline{D}_r$ from that given by Eq.(2) are due to the motion of two quasars in a pair to approaching one another, such peculiar velocity should then have the order of one thousand Km/sec.

4. Conclusion and Discussion

The velocity v_{up} given by Eq.(12) is, obviously, model-dependent. A key point in the developed model is to assume that all pairs are clustered, so that, in all pairs, two quasars are moving toward each other. As mentioned above, quasars in the sample clustered weakly on the scales of 50-100 Mpc. This seems to be evidence that quasars are just in the initial stage of forming clusters with a scale of about 50-100 Mpc. In this case, the assumption is simple, but reasonable.

Moreover, Table 1 shows that all deviations of $\bar{D}_r$ from that given by Eq.(2) are less than 6%, namely, the distribution of pair orientations is rather isotropic. This also implies that the clustering on the scale of about 50-100 Mpc is in the stage of spherical collapse. At this stage, the dominant component of peculiar velocity is given by the motion of collapsing.

Anisotropic clustering will also lead to a deviation from the distribution given by Eq.(1). Such deviations, however, depending on the orientation of the clusters, are sometimes positive, or $\overline{D}_r > \frac{3}{8} D_{max}$, and sometimes negative, or $\overline{D}_r < \frac{3}{8} D_{max}$. Therefore, statistically, the maximum of v_{up} would be larger than quasar's peculiar velocity. Therefore, it is reasonable to use one thousand km/sec as an upper limit to the peculiar velocity of quasars.

Finally, it is not difficult to extend the method developed here to other models of peculiar velocity. Our simple model demonstrates the possibility and the effectiveness of finding information about peculiar velocity from current data on quasars.

References

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Table 1, Upper limit to Quasar Peculiar Velocity

sample	D_{max} (Mpc)	$\overline{D}_r$ (Mpc)	$\frac{\overline{D}_r - \frac{3}{8} D_{max}}{\frac{3}{8} D_{max}}$	V_{up} (Km/sec)
(02^h, -50^o)	50	19.8	5.6 %	888
(02^h, -50^o)	100	35.9	4.2 %	1280
(22^h, -18^o)	50	18.0	4.0 %	576
(22^h, -18^o)	100	39.7	5.9 %	1760

Figure captions

Fig.1, Distribution of the number of quasar pairs against the pair's size D for the Savage-Bolton sample of $(02^h, -50^o)$ (solid line) and an average of 10 Monte Carlo samples by randomization of angular coordinates α and δ (dashed line).

Fig.2, Distribution of the number of quasar pairs against the pair's size D for the Savage-Bolton sample of $(22^h, -18^o)$ (solid line) and an average of 10 Monte Carlo samples by randomization of angular coordinates α and δ (dashed line).

Fig.3, Histograms of pair numbers with respect to radial distance D_r for subsamples of (a) D_{max} = 50 Mpc; and (b) D_{max} = 100 Mpc, in the region $(02^h, -50^o)$. Solid curves are the isotropic distribution of Eq.(1).

Fig.4, Histograms of pair numbers with respect to radial distance D_r for subsamples of (a) D_{max} = 50 Mpc; and (b) D_{max} = 100 Mpc, in the region $(22^h, -18^o)$. Solid curves are the isotropic distribution of Eq.(1).

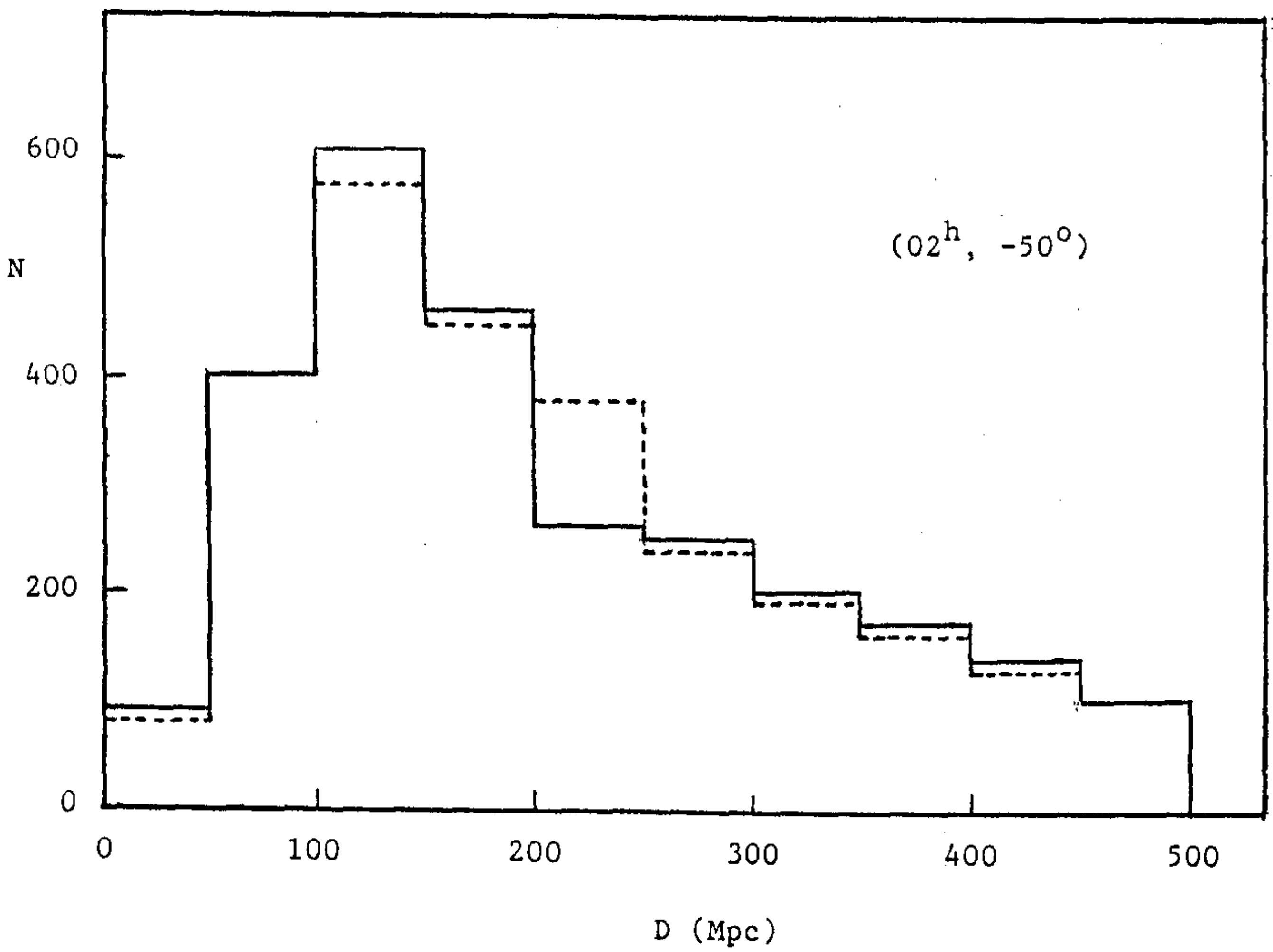


Fig. 1

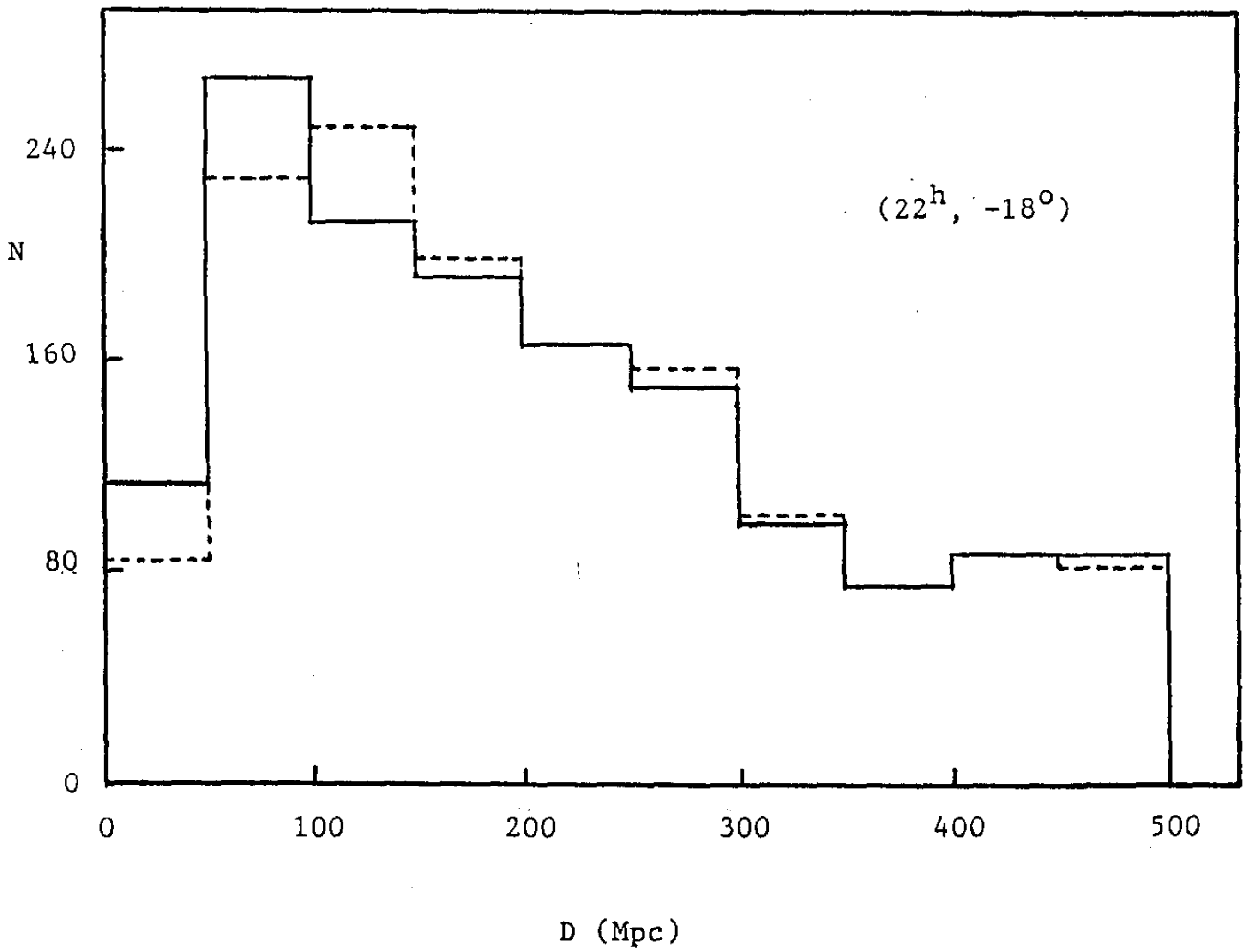


Fig. 2

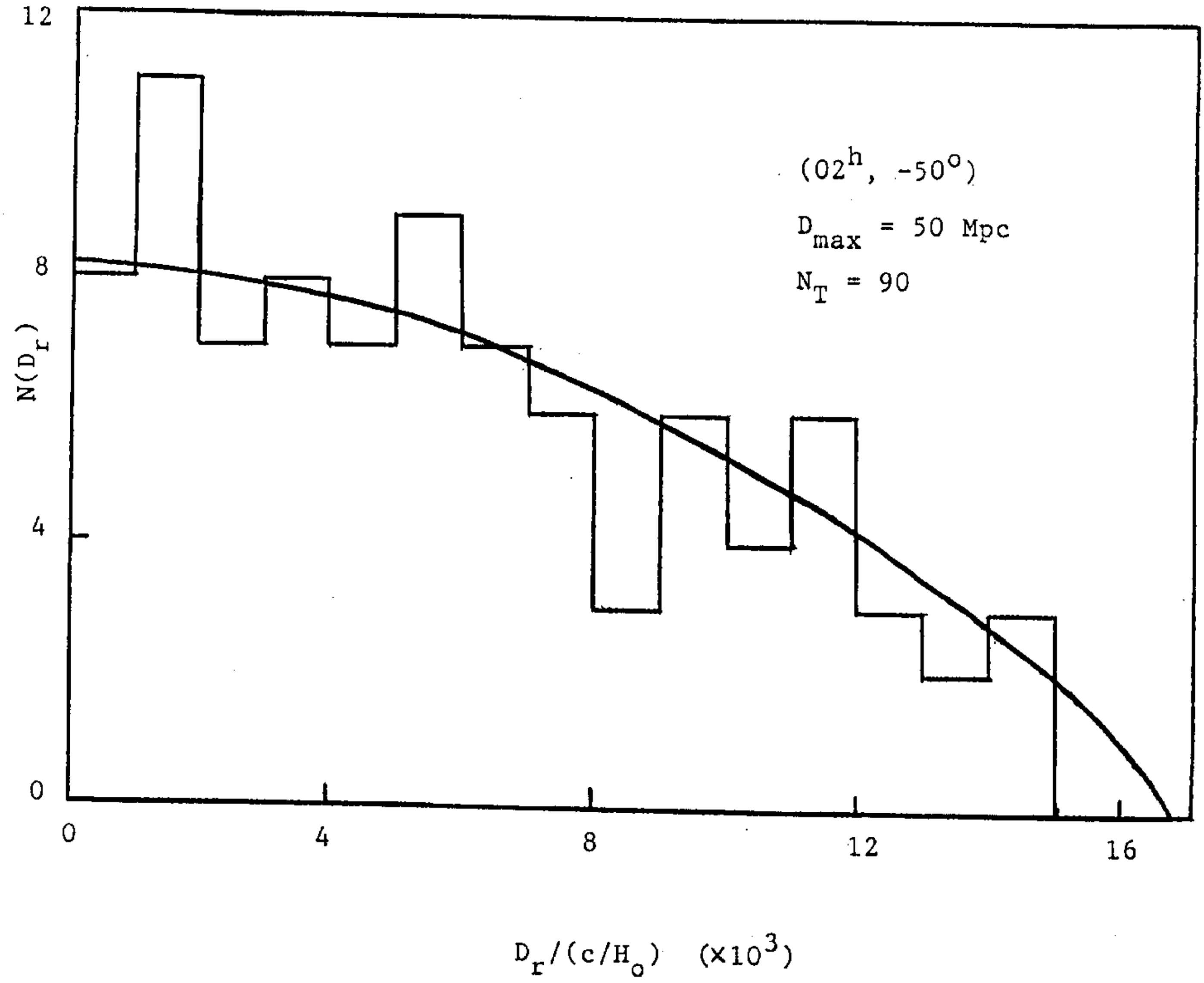


Fig. 3a

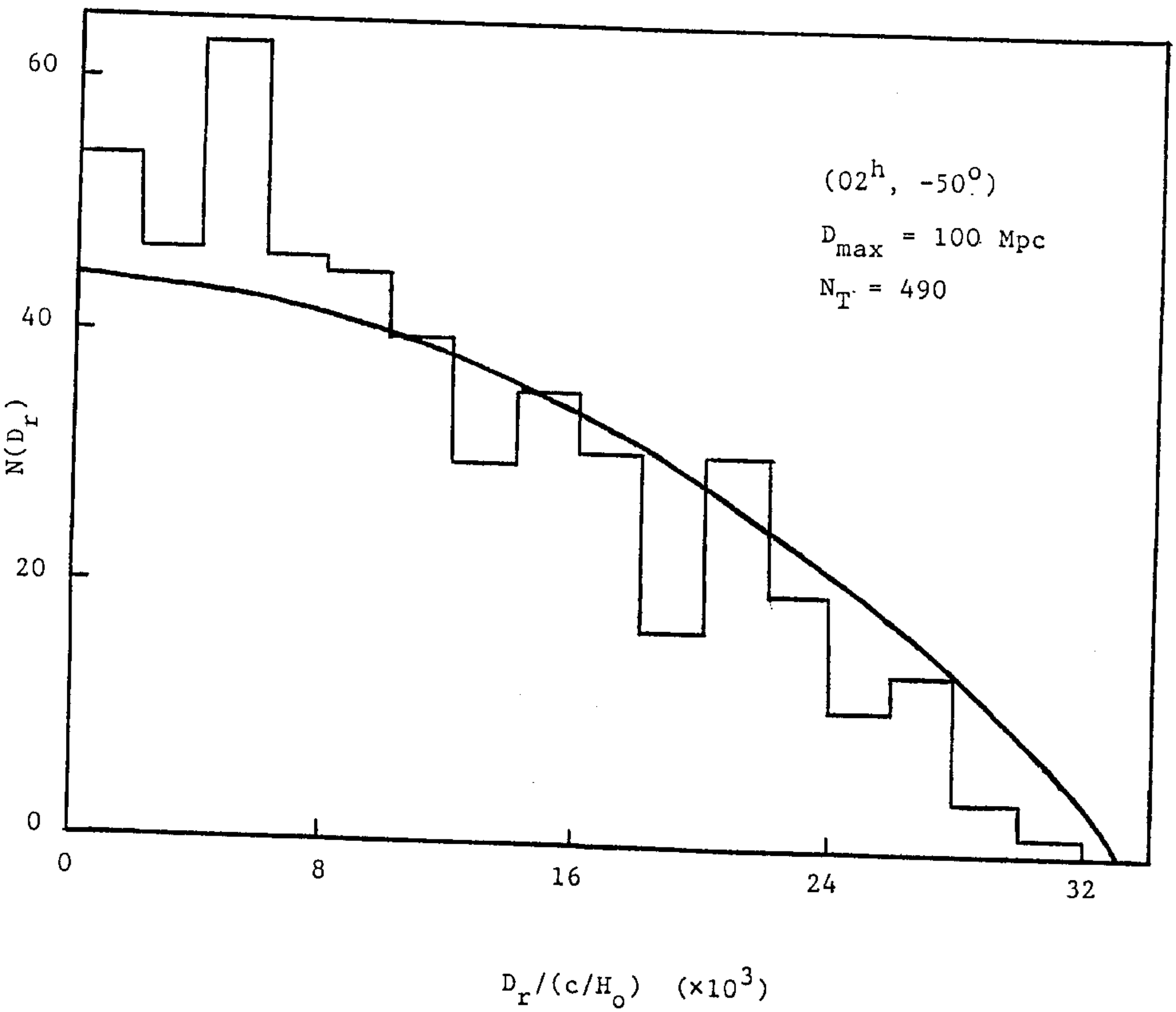
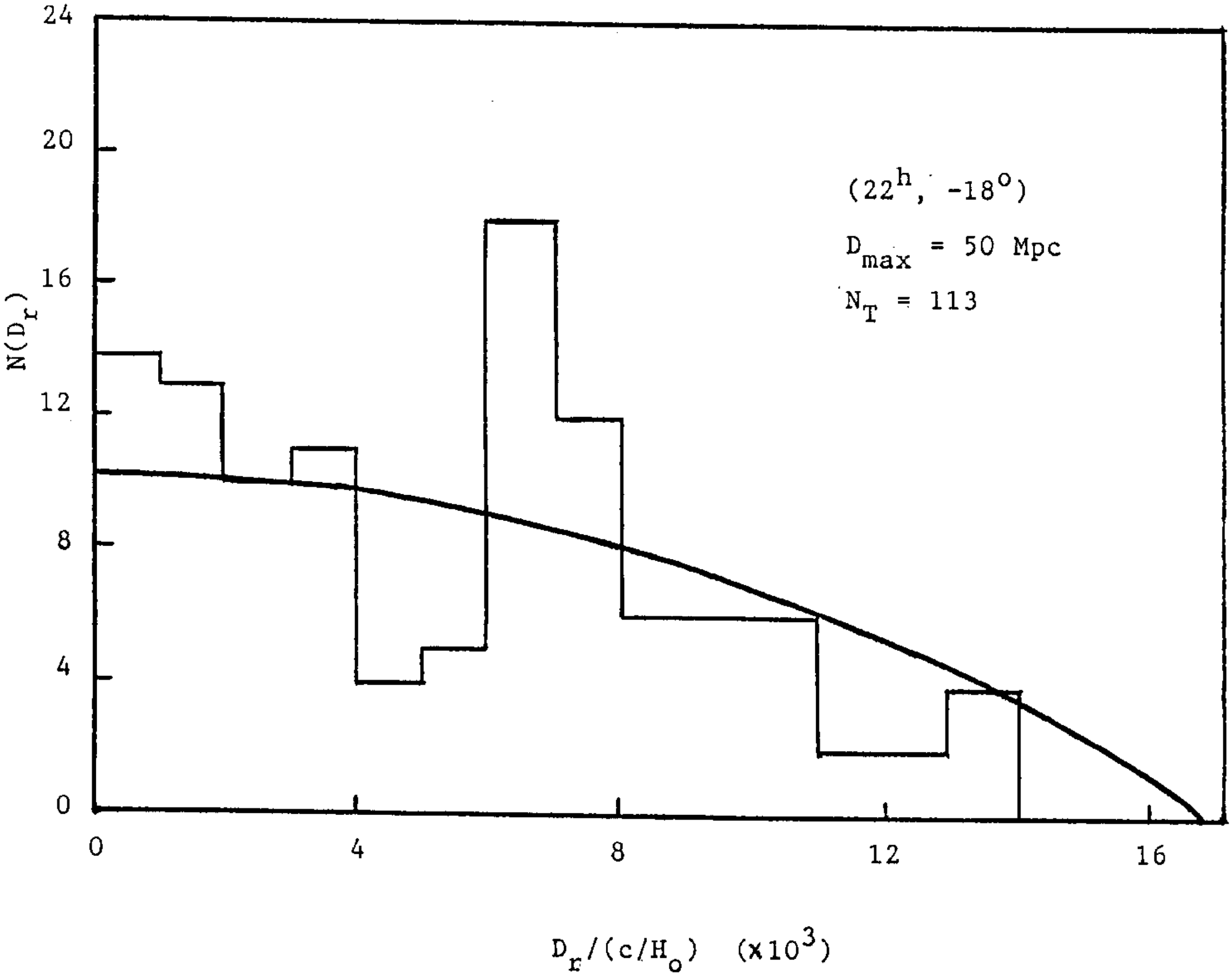


Fig. 3b



24
20
16
12
8
4
0
$N(D_r)$
$(22^h, -18^o)$
D_{max} = 50 Mpc
N_T = 113
0
4
8
12
16
$D_r/(c/H_o)$ $(\times 10^3)$

Fig. 4a

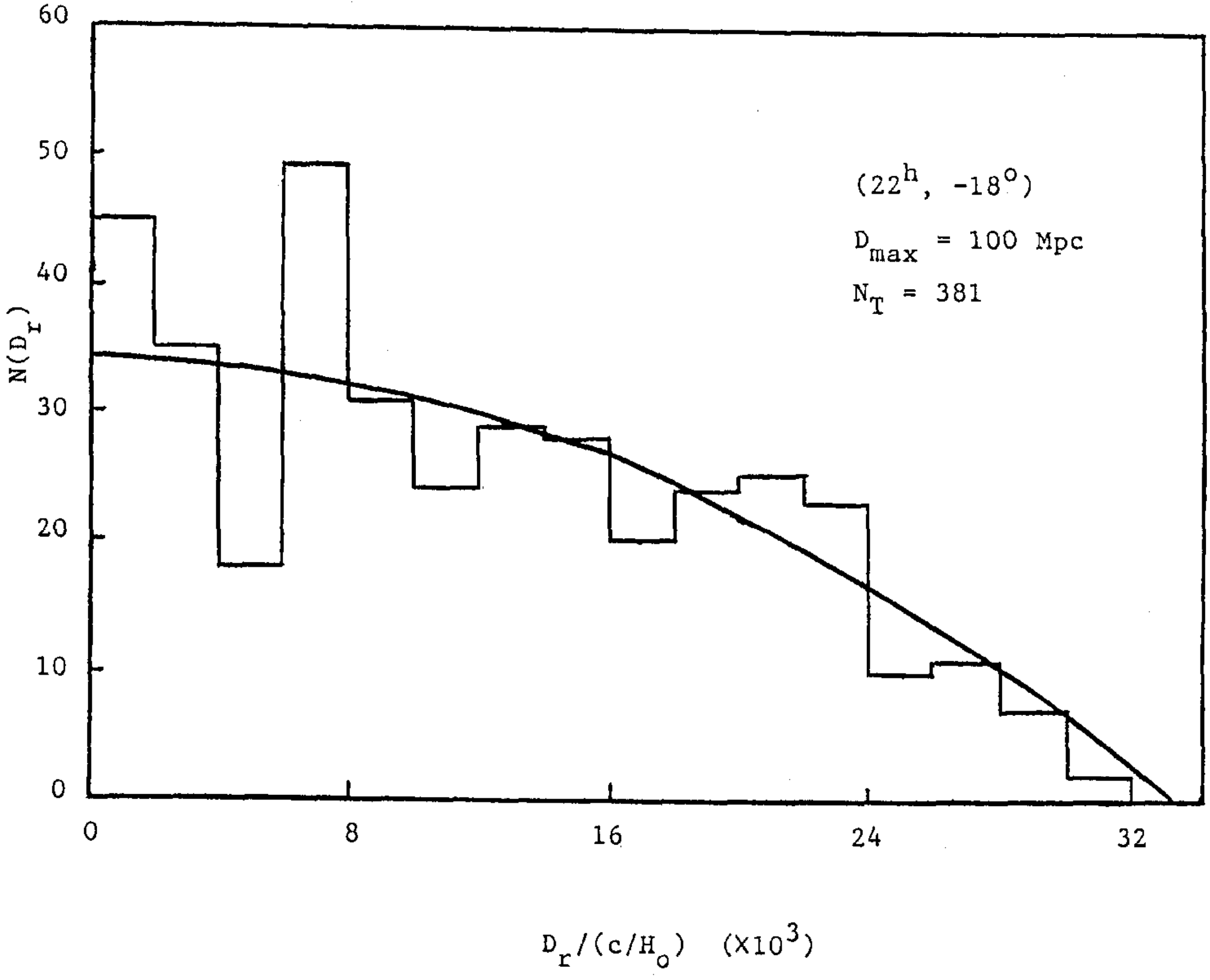

60
50
40
30
20
10
0
N(D_r)
(22^h, -18°)
D_max = 100 Mpc
N_T = 381
0
8
16
24
32
D_r/(c/H_o) (X10^3)

Fig. 4b